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An investigation on latent image Fading in Ilford G-5 emulsions

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With 14 figures in the text

Introduction

The mass of charged nuclear particles observed in nuclear emulsions can be found from simultaneous measurements on their tracks of any two of the quantities residual range, ionization and small angle scattering. The combination of residual range and ionization will give, as a rule, the most accurate values of the mass for a given track [1]. The accuracy attained will essentially depend on the accuracy with which the ionization can be measured. This measurement depends on grain counting, gap counting, gap length measurements or photometric methods. It is always made relative to tracks of known charge, mass and velocity.

Even if the measurements themselves are made with the highest possible accuracy there is still a possibility of systematic errors. Such errors may be due to local differences in the sensitivity of the emulsion, to uneven development and to fading. The latent image in the emulsion will decrease in strength under certain conditions, and errors will appear if the tracks are formed in the emulsion at different occasions during a period when the conditions promote fading. Fading errors are usually quite small in the emulsions which are nowadays almost exclusively used in cosmic ray studies, viz. Ilford G-5. Albouy and Faraggi [2] have proved the stability of the latent image in connection with an investigation of a method to deplete background tracks by means of accelerated fading. In connection with another investigation Belliboni and Merlin [3] have studied fading at 100 % relative humidity and 30° and 15°C at ionizations above 5 keV/μ. These investigations, however, give but limited information about the influence of fading under the conditions which the emulsions may be exposed to in connection with cosmic ray experiments. It thus seemed desirable further to investigate the fading effect.

In a preliminary investigation [4] the author has measured the fading of proton tracks with an energy loss of about 12 keV/μ with the plates kept at temperatures of 3°, 20° and 30°C and relative humidities of 25 % and 69 %. In the present paper the work has been extended to proton tracks with an energy loss above 3 keV/μ (residual range 10 mm), temperatures between 3° and 30°C and relative humidities between 13 % and 75 %. The plates were stored under those conditions up to 2 months.

Treatment of the emulsions

The investigation was confined to Ilford G-5 emulsions with a thickness of 200 μ coated on glass. The plates were treated in two different ways.

Series I included emulsions intended for measurements of fading as a function of temperature and humidity. Each plate was exposed to protons in a cyclotron. They were then stored under controlled and constant conditions and were finally exposed once more in such a way that the new particles entered the emulsions at right angles to the old tracks. The plates were then processed as soon as possible.

Series II was intended for an investigation of the progress of fading with time. All the plates were stored under constant conditions known to cause rather severe fading (25°C, 75 % RH). They were repeatedly taken from the depository and exposed anew, and were then immediately put back in again. The last exposure in every plate took place just before the development. Exposures were made on six different occasions.

The procedure was chosen in order to provide for comparisons between faded and unfaded tracks in the same emulsion in each case. This made it possible to avoid errors caused by differences in development and background.

Exposure

The exposures were made in the 190 MeV synchrocyclotron at Uppsala. The plates were wrapped separately in light-proof paper and placed one after the other outside the cyclotron about 2 m from the aluminium window where they were hit by protons scattered from a target. The protons were slowed down by means of a 3 cm aluminium plate, to increase the probability of the particles to come to rest in the emulsion. The aluminium plate was placed at a distance of 35 cm in front of the emulsions which were screened by lead in such a manner that the proton beam entered the emulsions with an aperture less than 20° in the horizontal plane. The plane of the emulsions was almost parallel to the proton beam. The time of exposure was chosen to give a track density in the emulsions corresponding to 10–25 particles per mm^2 in a plane normal to the beam.

Storage

The plates were kept unwrapped over saturated salt solutions in light-proof desiccators. These were placed in thermostates. The salts were chosen from O'Briens tables [5]. This method was chosen since saturated salt solutions will retain constant humidity irrespective of the water absorbed or evaporated during the storage. Besides, the relative humidity for most salt solutions is almost the same at different temperatures. The values of temperature and relative humidity are collected in Table 1.

In connection with the exposures it was unavoidable to keep the plates at uncontrolled conditions. However, humidity and temperature never reached values where a measurable amount of fading were to be expected. Errors from this cause are therefore less probable.

Adaption to change in humidity

Since the plates were subject to changes in humidity on different occasions it is important to know the time required for them to adapt their water contents to the ambient relative humidity. For this purpose the emulsions were weighed repeatedly

Table 1. Relative humidity and temperature for the plates.

Salt	Relative humidity %	Temperature			
		3°C	20°C	25°C	30°C
NaCl	75	U 101	U 105	U 123 U 124	
NaCl–$NaNO_3$	69			U 111	
NaCl–Cane Sugar	63			U 110	
$Na_2Cr_2O_7$	52			U 109	U 117
$CaCl_2$	31			U 108	U 115
LiCl	13			U 107	U 113

and the changes noted. The emulsions, if not dried entirely, will resume the original weight within 1 ‰ when brought back to a surrounding with the original humidity. This seems to show that changes in weight are due to water being absorbed or evaporated.

Ilford has published values of the water contents in their emulsions at different relative humidities [6]. It was found that these values may differ slightly from batch to batch. At humidities between 75 % and 50 % and room temperature, 3–4 days will be sufficient for a 200 μ emulsion to attain equilibrium. About 80–90 % of the total change in weight will take place during the first day. If the humidity is low this time is longer. This is, however, of less importance in this case as no fading was observed at low humidity.

Hysteresis effects in an undeveloped emulsion are unimportant. Its magnitude is equivalent to a change of about one per cent of relative humidity. If the relative humidity is kept constant the water contents will decrease as temperature increases. An increase in temperature of 10° at 75–50 % RH will cause a change in weight equivalent to a decrease in relative humidity of 2–4 %. Oliver [7] made the same observation in C-2 emulsion and his values are in excellent agreement with the present values.

At the different exposures an emulsion should always have about the same water contents. However, the plate should not be kept outside the depository longer than is absolutely necessary. The emulsions of series I were allowed to adapt themselves to laboratory conditions (20°C, ca. 55 % RH) for at least one day. The emulsions of series II were consistently exposed within half an hour after they were taken from the desiccator. A long time of adaption would in this case influence the effect to be measured too much.

Development

The plates were developed in diluted ID 19 (1 part developer, 2 parts water) in a temperature cycle consisting of 60 min. soaking at 3°C and 90 min. dry plate development at 12°C. All emulsions mentioned in this paper were developed simultaneously but for one (U 125). After 60 min. soaking at 3°C this plate was placed immediately in a stop bath.

Table 2 gives the age of the plates at the different stages of the experiment.

Table 2. Age of the plates on different occasions.

Series I U 101, U 105, U 107, U 108, U 109, U 110, U 111, U 112, U 113, U 115, U 117, U 125		Series II U 123, U 124	
First exposure	24 d.	Storing started	23 d.
Storing started	28 d.	First exposure	35 d.
Storing ended	86 d.	Second exposure	50 d.
Second exposure	91 d.	Third exposure	60 d.
Development	99 d.	Fourth exposure	70 d.
		Fifth exposure	80 d.
		Sixth exposure	91 d.
		Storing ended	91 d.
		Development	99 d.

Measurements

All measurements were made by means of a photometric apparatus of the type first described by von Friesen and Kristiansson [8] and further developed afterwards [9, 10]. The current from the photo-multiplier was registered on a Leeds and Northrup Speedomax recorder, type G. The mean track width (MTW) was determined in the usual way from three readings. The first reading gives the current U corresponding to the case where the image of the track falls on the slit, the second and third readings give the current corresponding to an empty slit. In this case the track falls 3.1 μ from the axis of the slit, the width of which was 2.45 μ. The mean of the latter readings is called U_0. The MTW is calculated in relative units as

$$S = k \, \frac{U_0 - U}{U_0} \, .$$

k is a normalizing factor making $S = 100$ at $R = 0$, for unfaded tracks. k is a constant for each plate. The tracks were always adjusted parallel to the x-motion of the microscope stage and the residual range was measured by means of the micrometer which provides the x-motion.

The position in depth of the track in the emulsion was measured relative to the thickness of the emulsion by means of the fine adjustment focusing device of the microscope. The distance from the glass is given in microns on the assumption that the thickness of the emulsion has been 200 μ.

Selection of proton tracks

Position in the emulsion

In each plate an area of 20 by 20 mm was chosen in such a manner that no part was nearer to the edges than 10 mm. The area was scanned and a number of proton tracks from the different exposures and of sufficient length was picked out for further analysis.

There are reasons to expect a more pronounced fading at the surface of the emulsion than in the interior. This was subject to a special investigation (Fig. 4). It is evident from Fig. 4 that the fading effect is constant in the bulk of the emulsion but larger in a surface layer, the thickness of which depends upon the amount of fading. In most cases it is safe to assume constant fading below a layer 30 μ from the surface. The present investigation has been confined to the region of constant fading. The following condition has been fulfilled in the measurements:

1. The tracks must not pass closer to the surface than a distance which depends on the degree of fading. This distance has been 30 μ as a rule, but 40 or 50 μ in cases of severe fading.

As a rule all tracks which came closer to the glass than 30 μ were also excluded.

Direction of the tracks

It is important that the tracks really originate from the exposure which one supposes. With the arrangement used at the exposures the protons cannot hit the plate if they deviate more than 10° from the direction of the beam, provided that they have not suffered scattering in the immediate vicinity of the plate. In order to estimate the relative number of scattered protons some plates were exposed only once. These were scanned for tracks at right angles to the exposure. No such tracks were found. Cosmic Ray tracks may also appear in the plates. In order to study this source of error, a plate was stored for 7 months in a similar way to that of the plates exposed in the cyclotron. The number of measurable tracks was so small that it seems highly improbable that any tracks of Cosmic Ray origin are included in this material. Besides, random tracks with a MTW value deviating too much from the value of other tracks in the same group would be easy to observe and discard. Thus, possible random tracks are of little importance for the results. The following selection rule was used:

2. The direction of a track entering the emulsion may not deviate by more than 10° from the mean direction of the beam.

At the same time the direction of the track must not deviate too much from the plane of the emulsion since this would require a new correction. Kristiansson [9] has discussed the influence of the inclination of tracks, and he has shown that the correction is small if the slit width lies between 2 and 3 μ. With my slit width, 2.45 μ, the following rule, based on Kristiansson's work seems to be satisfactory:

3. The dip angle of a track must not exceed 15° in the unprocessed emulsion.

Disturbances

In photometric measurements of this kind the light falling in the photo-multiplier will have to pass through a certain volume of emulsion. The presence of background grains and other tracks within this volume will influence the light flux and reduce the photo-current. In practice such disturbances can never be avoided and they will increase in magnitude as the time elapsed between manufacture and processing is extended. They will contribute to the width of the statistical distribution of mean track widths and their extreme values can be taken care of by an appropriate choice of cut off. This will be discussed later on. In one particular case it is possible to discard a disturbed part of a track at once, that is when a foreign track runs parallel to the

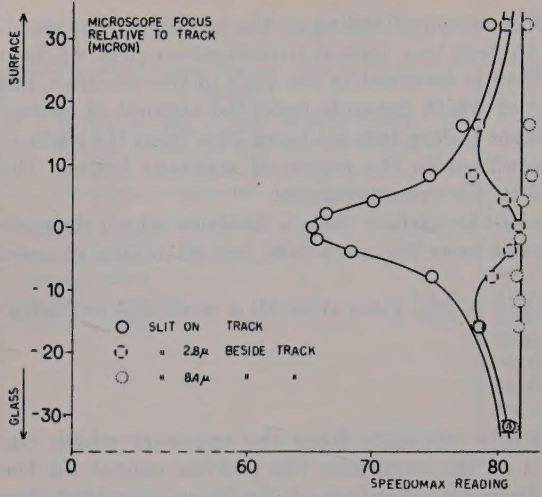

Fig. 1. A horizontal track was adjusted either in the slit or beside it and the microscope was focused on different levels above or below the track. The corresponding deflections were recorded by the Speedomax Recorder. It is found that a track will influence the determination of MTW for other tracks in a volume approximately ± 20 μ in height and ± 10 μ in width.

track to be measured. This is a very common case for plates exposed in a cyclotron. The consequence of this is that the track density must be kept very low when photometric measurements are to be made. In my case an exposure giving about 25 tracks per mm^2 proved to be best. The foreign track acts differently on the three readings of each determination of the MTW, and therefore causes an erroneus result.

It is possible to get an idea of the magnitude of this effect by measuring the photocurrent when the microscope is focused on different areas around a track. For this purpose a horizontal proton track was chosen, in the middle of an emulsion with very few background grains. Measurements were made close to the end of the track. The mean values of the readings are plotted in Fig. 1 versus the distance from the track in height, with the distance sideways as a parameter. If the microscope is focused in the plane containing the track, no decrease in current is observed, provided that no part of the track covers the slit. When the slit covers the track completely the current will have a minimum. If the microscope is focused in some other plane the photo-current will still have a minimum provided that the slit is straight above or below the track. This minimum is more shallow. The influence of the track is observed for some distance to each side, depending upon the difference in height between the track and the slit and the numerical aperture of the optics. Further away the influence of the track will be less than the background.

By means of the curves in Fig. 1 which apply to a dense track the following rule may be formulated:

4. Parallel tracks must not come closer than ± 10 μ sideways or 20 μ above or below the track to be measured.[1]

Actually it is rather rare that all the four rules which are discussed above are fulfilled along the whole length of a track. In practice therefore, only the second rule was maintained strictly. Tracks were actually measured which ought to be discarded due to any of the other rules, provided that only a short length was affected. Those parts of the tracks for which the rules were not fulfilled were omitted.

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[1] These values are distances geometrically measured.

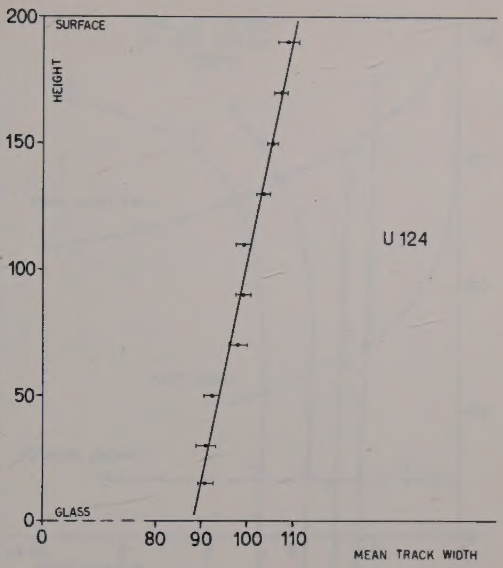

Fig. 2. Relation between MTW and height in a representative case. MTW is normalized to 8.5 keV/μ and to the central layer of the emulsion. In all plates the results were best represented by straight lines. All observations are reduced to the central layer of the emulsion by means of height-depending factors calculated from such curves.

Corrections

Depth correction

The MTW's S which are measured depend upon how deep down in the emulsion the track is situated. This effect, which has a pronounced influence upon photometric measurements of this kind, has been treated in detail by Kristiansson [11, 12]. In order to determine the correction, he used protons in the range interval 0–3 mm chosen from a mixture of protons, deuterons and tritons after a preliminary correction based upon this mixture. In my case the proton tracks from the last exposures were used to calculate a correction curve. A separate curve was made for each plate. In individual cases the plotting of the curve may be a little uncertain due to statistical fluctuations. If the material from several plates with approximately the same degree of fading are put together it is obvious that the curve correlating MTW and height in the emulsion is best approximated by a straight line between 30 and 170 μ. The correction curve for each plate was for this reason calculated by the method of least squares under the assumption of linearity. The change of measured MTW was about 0.1 % per μ, the largest value observed being 0.18 % per μ. A typical example is given in Fig. 2. By means of correction factors calculated from the curves the MTW's were reduced to the central layer of the emulsion.

Cut-off

Each measurement comprised a length of the track of 32.5 μ and consecutive measurements were made along each track. This will give in round numbers 30 individual MTW values per mm. Among those values exceptional, abnormal values will appear as a result of the disturbances which have been discussed already. It is convenient

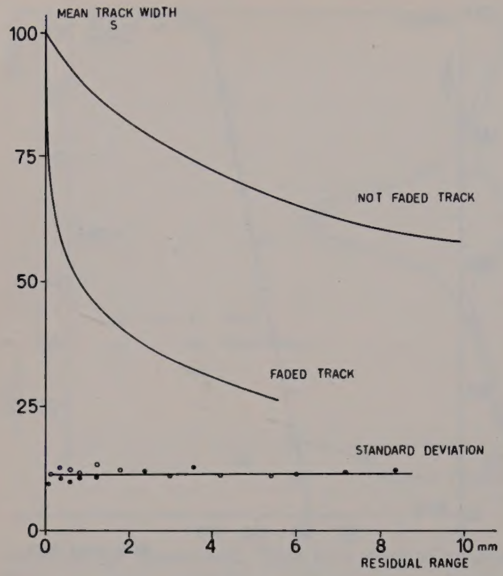

Fig. 3. The standard deviations in MTW for single observations plotted to the same scale as the corresponding values in MTW. As the standard deviation is almost constant, a constant cut-off value was used in each plate.

to eliminate those values by adapting a suitable cut-off. It is doubtful whether a general cut-off rule can be applied in this case where we have tracks of very different degree of fading and MTW values varying between 25 and 100. This problem was examined in some detail. An emulsion with rather severe fading was chosen (U 124). After the height corrections had been applied, the standard deviation of the MTW values was calculated and plotted as a function of the residual range for faded and unfaded proton tracks (Fig. 3).

It is obvious that σ changes very little with MTW irrespective of fading, and one ought to be permitted to adapt a single cut-off to faded and unfaded tracks in the same emulsion. For the example shown in Fig. 3 a cut-off value of ± 25 units was used leading to the rejection of 2.5 % of the values. In other emulsions with less fading, the influence of background grains is greater which leads to larger standard deviations in the MTW. In such cases the cut-off was made at correspondingly larger values. Kristiansson found for plates of about the same age that the standard deviation due to background will contribute rather more to the total standard deviation than the deviation due to variations in grain density in the track itself [9].

Results

Fading as a function of the depth in the emulsion

This effect was studied in a plate stored at 75 % RH and 25°C (U 124) exposed at four different times during the storage period. From each exposure about 15 tracks were chosen, 1.1 mm in length fulfilling the conditions 2, 3, and 4 and distributed as evenly as possible over different heights in the emulsion. In Fig. 4 the relation between height and MTW at a residual range of 0.84 mm is plotted. The MTW values were normalized in such a way that the end of an unfaded proton track gave the value 100 in the middle of the emulsion.

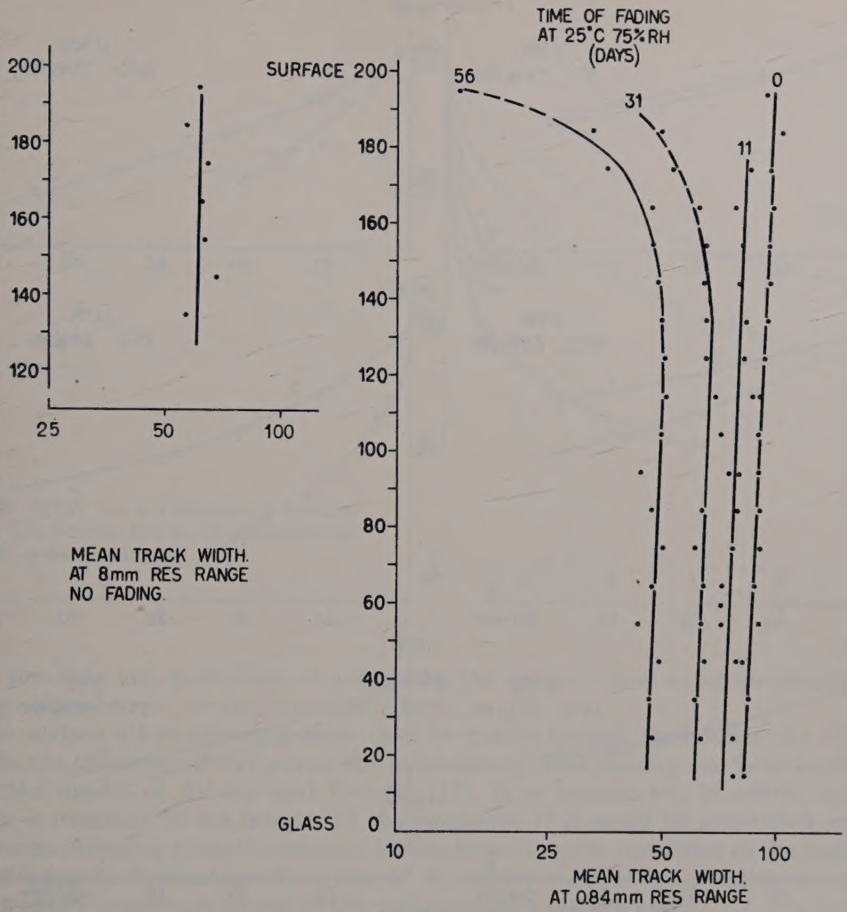

Fig. 4. Relation between height and MTW for proton tracks with different fading in the same plate. The curves are calculated in a similar way as the curve in Fig. 2; however, the normalization was made to the end of unfaded tracks (0 days). The correction factors which mainly depend on development and opacity of the emulsion, were calculated from these tracks. If these factors are used for all tracks the curves will be straight vertical lines in the interior of the emulsion. Fading is thus constant in the whole emulsion but for the surface layer.

For the tracks of the first exposures, 31 and 56 days before the final exposure, an obvious decrease in MTW was found in the surface layer. This decrease can easily be observed in the microscope. It has been checked by grain counting and applies to faded tracks in all emulsions where a sufficient amount of fading has taken place. A surface layer of some tens of microns is affected. The decrease in MTW at the surface was not observed in any case at greater depth than 60 μ. Below this depth the MTW versus height curves are parallel on the logarithmic scale. Then the relative decrease in MTW due to fading is constant.

Tracks from the last exposure immediately before the processing, do not show this decrease in MTW at the surface. This applies to small as well as to large values of MTW, which may be seen from the values at 8 mm residual range in Fig. 4. These

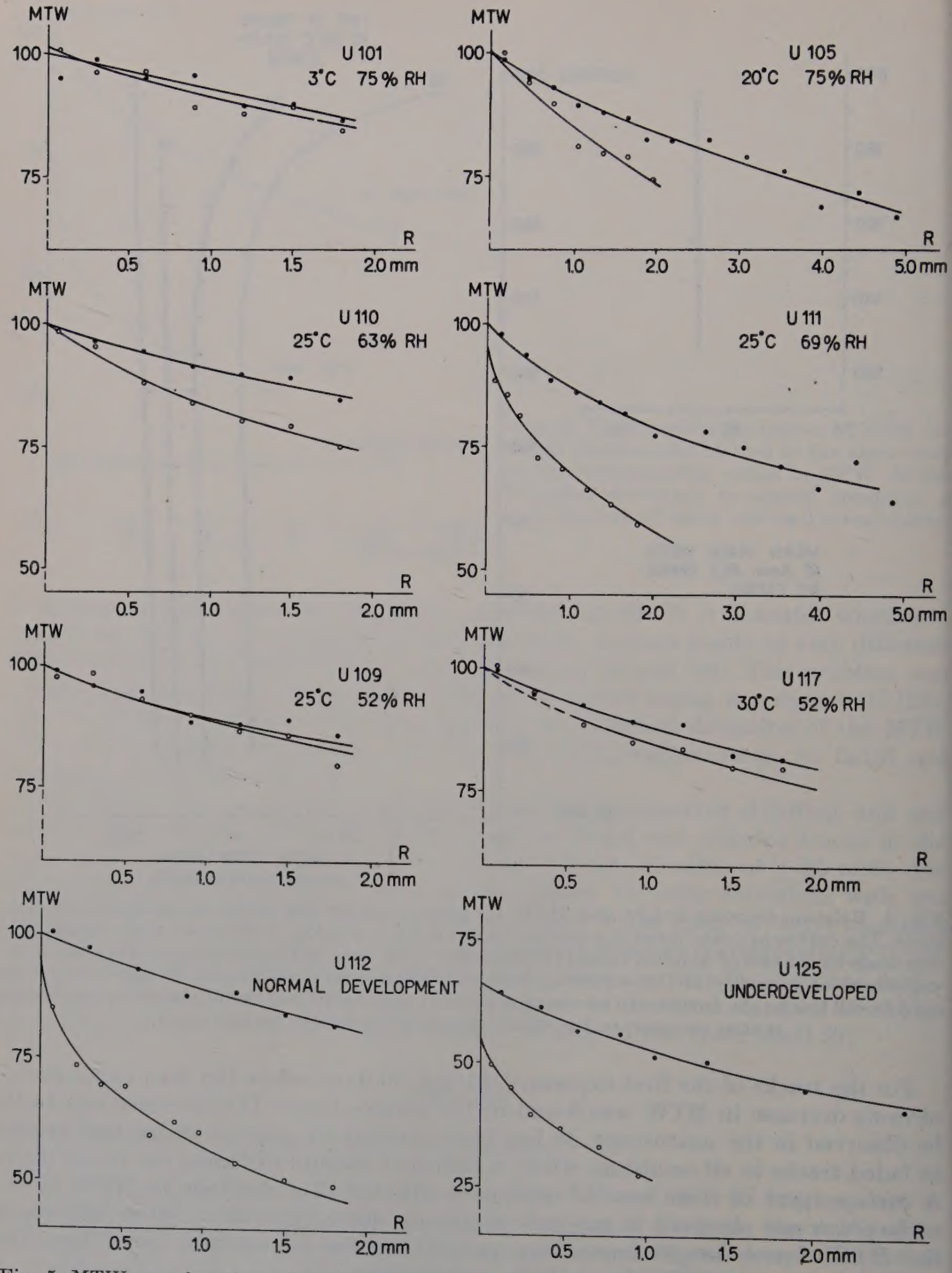

Fig. 5. MTW as a function of residual range for faded and unfaded proton tracks in a number of emulsions treated in different ways.

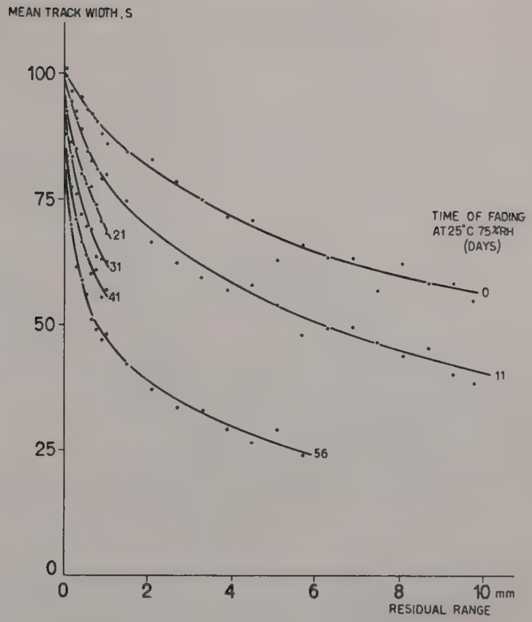

Fig. 6. MTW as a function of residual range for proton tracks of different age in the same emulsion.

facts preclude any possibility of explaining the surface effect as an emulsion-, processing-, dissolution-, or instrumental effect.

The surface effect observed must thus be due to fading. Most likely the effect is due to the influence of oxygen in the atmosphere. This assumption is in agreement with the results of Albouy and Faraggi [13]. It is remarkable, however, that the fading is constant in the interior of the emulsion. If it could be attributed entirely to oxygen diffusing from the surface, in combination with the water in the emulsion, a continuously decreasing effect was to be expected. It is not possible to explain the observed constancy by aid of the measurements made so far.

Faded mean track width as a function of residual range and energy loss

Since the whole material was standardized to the central layer of the emulsion it is possible to calculate the average proton MTW-range curve for each exposure. The results are given in Figs. 5, 6 and 7. For plates of series II exposed several times, the MTW is plotted as a function of residual range as well as a function of the logarithm of the energy loss. The energy loss was calculated from the ranges observed, by means of Barkas and Young's tables [14]. In Figs. 6 and 7 the tracks faded for 56, 31, 11, and 0 days are from plate U 124 and the tracks faded for 41 and 21 days from plate U 123. Both plates are of the same batch and were treated together during the whole experiment.

Fading as a function of time, temperature, and relative humidity

In the literature the degree of fading is often given by a fractional number $T = (N_1 - N_2)/N_1$, where N_1 is the number of grains per unit length in unfaded tracks

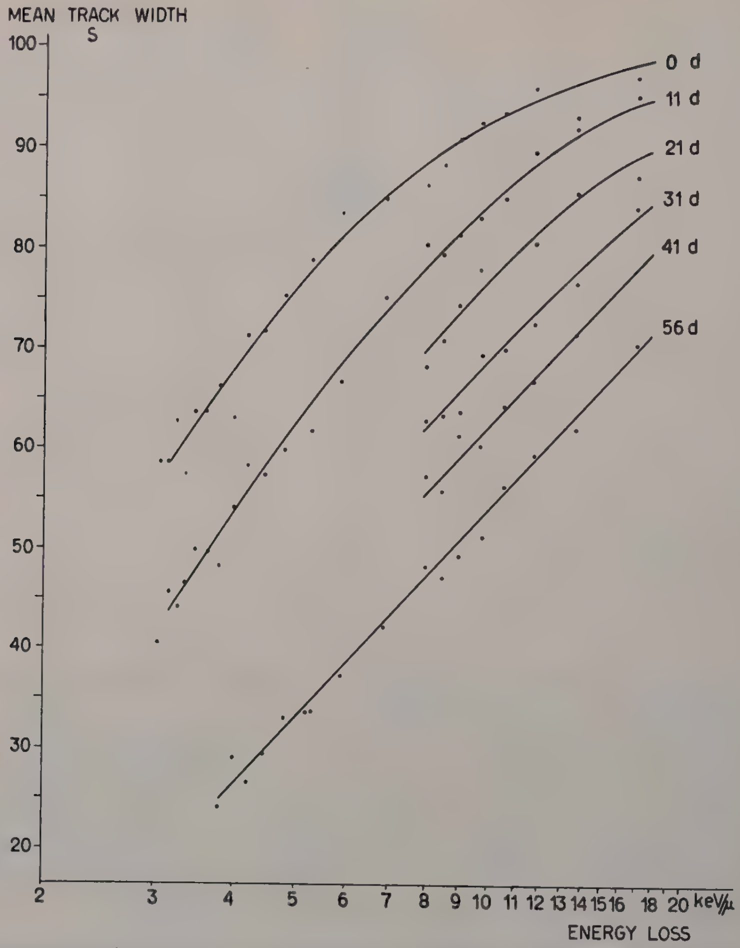

Fig. 7. The same material as in Fig. 6 plotted as a function of energy loss on a logarithmic scale

and N_2 the same number in faded tracks with the same energy loss. In analogy with this, fading for tracks measured photometrically may be given by a quotient $F = (S_1 - S_2)/S_1$, where S indicates the mean track width. F can easily be calculated also from a limited material. However, it is a function of the degree of development as well as of the energy loss. This is obvious from Fig. 8a where F is plotted as a function of the energy loss for two plates with the same manufacturer's number and the same storing conditions, but different development. One (U 112) was processed according to the standard method, whereas the other (U 125) was developed only during the soaking period at 3°C for 60 minutes. F is larger if the ionization is low and if the degree of development is low.

It is evident that it is desirable to find another function of fading less sensitive to development and method of measurement. This is possible in many cases. In Fig. 7 the curves are very similar and the difference in $\log(dE/dR)$ between adjacent curves

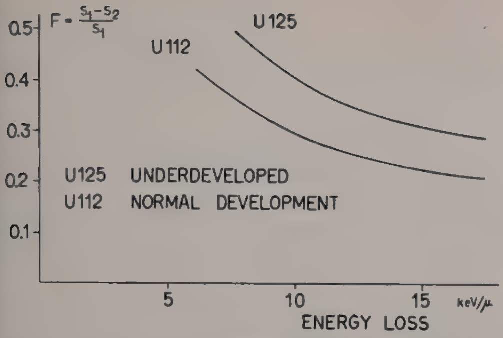

Fig. 8a. The fading quotient, F, for two similar emulsions with different development.

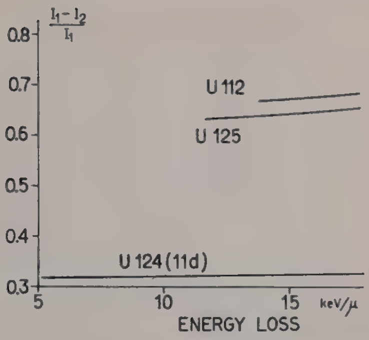

Fig. 8b. Fading expressed as the relative decrease in energy per unit length. The original energy is calculated from the range–energy loss curve for protons. This way to represent fading gives results almost independent of original energy loss, especially if the effect has not advanced too much.

is approximately constant for different values of MTW. To the extent that this is valid, it means that a faded track will appear as if the energy originally absorbed per unit length has been diminished by a constant factor, independent of the energy. This is realized within the observational errors, if the reduction is less than $\frac{1}{3}$. The reduction being greater, the curves approach slightly at low values of ionization. Under those circumstances the apparent relative loss in energy is somewhat less for low than for high ionization. However, it seems to me that the relative loss in apparent energy might be a suitable measure for the fading of nuclear tracks in G-5 emulsions. In Fig. 8b the quotient $\phi = (I_1 - I_2)/I_1$ is plotted as a function of I_1 for U 112, U 125, and U 124 (11 d.). I_1 and I_2 will be defined in a following section.

A denfinite relation exists between MTW and the energy absorbed by the grains in unfaded tracks. The same relation seems to be a satisfactory approximation in slightly faded tracks if the energy absorbed is substituted by an apparent energy obtained by multiplying the absorbed energy by the factor depending on fading, which was mentioned above.

A faded track, characterized by a constant relative loss in energy, will appear as if it were due to a particle lighter than the real one, provided that the track is compared with unfaded tracks. This is evident from Fig. 9. Curve A represents an unaffected proton track and curve B a faded proton track. At the point 1 the energy

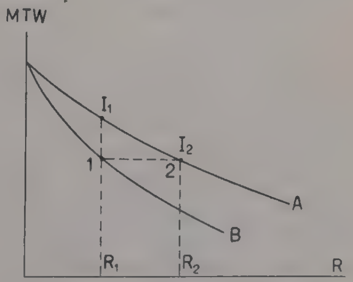

Fig. 9. MTW-residual range curves for faded tracks (B) and not faded tracks (A) in the same emulsion. The experiments show that I_1/I_2 is approximately constant if R is varied, and from this it is deduced that R_1/R_2 must be a constant too.

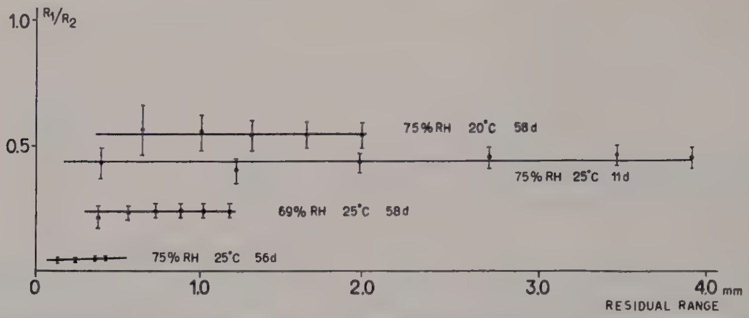

Fig. 10. The quotient R_1/R_2 as a function of residual range, R_1, for some representative cases. R_1 and R_2 are defined by Fig. 9. If curve B in Fig. 9 represented the track of a real particle, then R_1/R_2 gives its mass in units of the mass of particle A. Fig. 10 thus verifies that consistent mass values will be calculated from faded tracks in most cases. R_1/R_2 is called the apparent mass.

loss, dE/dR, was in reality I_1 but the measured MTW is equivalent to an energy loss I_2 only, corresponding to the point 2 on curve A. The energy–range relation for the particle A can be approximated by the following expression [15]

$$E = aR^b,$$

where a and b are constants for the whole interval and $0 < b < 1$.

$$I = \frac{dE}{dR} = a\,b\,R^{b-1},$$

$$\frac{I_2}{I_1} = \left(\frac{R_1}{R_2}\right)^{1-b}.$$

As I_2/I_1 is a constant for a track, this must be the case also for R_1/R_2. R_1 and R_2 are ranges corresponding to the same MTW and this is a quotient which is always used in emulsion work when the mass ratio is to be calculated between two different particles with the same charge. Determinations of this quotient for different MTW's along a track subjected to moderate fading will thus give consistent results, and it will be impossible to use the range-MTW method to prove the existence of fading in the region where I_2/I_1 is a constant.

The quotient R_1/R_2 determined in this way by comparison between a faded track and unfaded tracks is a convenient measure of fading where the influence on mass determinations is concerned. The quotient will be called the apparent mass and has been given in units of the true mass of the particles which caused the tracks.

In Fig. 10 the quotient R_1/R_2 is plotted as a function of R_1 for some typical cases. The points marked are calculated from the curves of Figs. 5 and 6. It should be mentioned that severe fading will imply a rapid decrease in MTW with range. The mean track width observed will then soon be below the lowest values available from the comparison tracks. Therefore, only a short distance at the end of a faded track can be used to determine R_1/R_2 in such cases. All results have been collected in Figs. 11, 12, and 13. The ratio R_1/R_2 has been plotted as a function of the relative humidity at constant temperature and time, as a function of the temperature at constant relative humidity and time and as a function of the time at constant

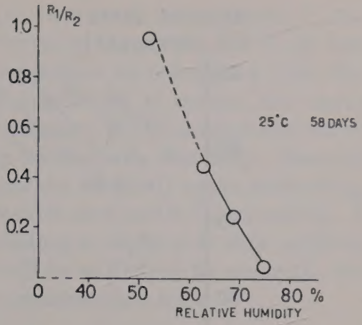

Fig. 11. Apparent mass in units of real mass as a function of relative humidity at constant temperature and time.

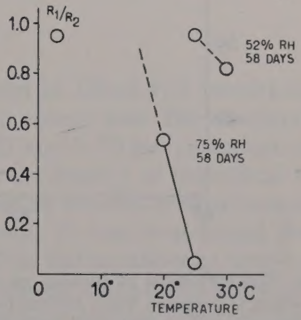

Fig. 12. Apparent mass as a function of temperature at constant relative humidity and time. The point at 3°C belongs to the 75 % RH, 58-day curve. For this relative humidity the apparent mass is very sensitive to changes in temperature around 20°C.

relative humidity and temperature. In one case (U 117) the apparent mass was calculated by the method of least squares according to Kristiansson [9]. As a rule, however, a graphical method was used.

Discussion

Fading and mass determinations

The G-5 emulsions are obviously very stable against fading under normal conditions. The sudden beginning of fading as certain values of temperature and relative humidity are exceeded is remarkable, however. After storage at 20°C and 75 % RH for 2 months the apparent mass of a particle is 0.54 in units of the true mass. An increase in temperature of 5°C to 25°C will give an apparent mass of only 0.05. At the same temperature but at 52 % RH no fading was found.

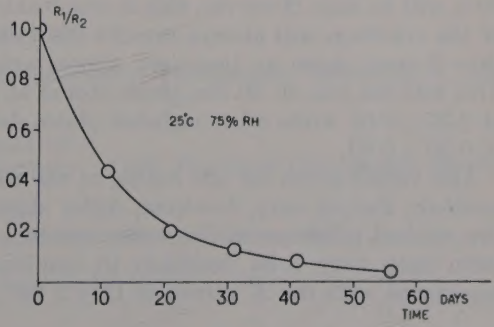

Fig. 13. Apparent mass as a function of time at constant temperature and relative humidity. The treatment indicated is very promotive to fading. After 3 days the apparent mass calculated from a proton track is about 1500 electron masses and after about 10 days it is equivalent to the mass of a *K*-meson.

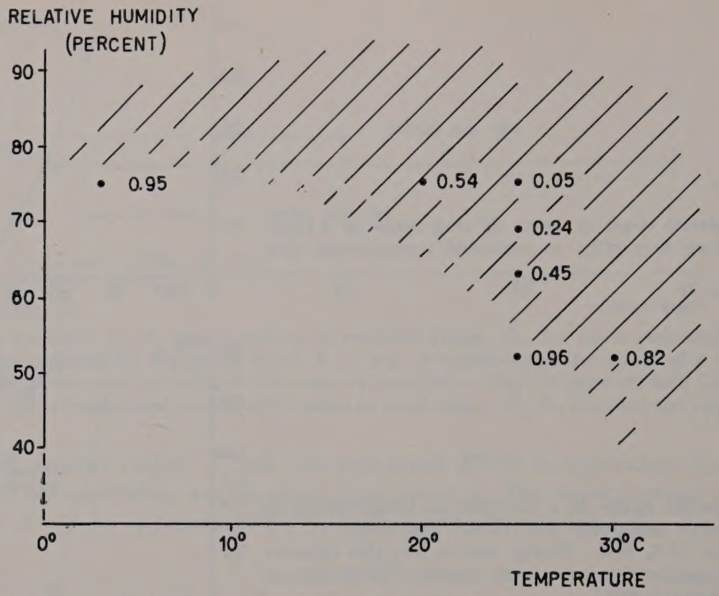

Fig. 14. The influence of fading on a track is given by the apparent mass. The apparent mass found when the plates were stored for two months under the specific conditions has been plotted in the diagram. The shadowed area gives a survey of the conditions which will give rise to fading during this time. The error in apparent mass is about 10 % and the values 0.95 and 0.96 which indicate slight fading at 3°C 75 % RH and 25°C 52 % RH are considered to be due to statistical fluctuations.

Storage at 75 % RH and 25°C for 3 days is sufficient to make a proton track in the matter of MTW appear as the track of a particle with the mass 1500 electron masses, if compared with unfaded proton tracks. Tracks of different age caused by particles entering the emulsion during the time of storage are unavoidable. If the conditions of storage at any time has been such as to induce fading, the masses of several of the particles found in the emulsion will be wrongly determined from measurements of ionization against range. The effect will be still larger at the surface of the emulsion.

The ordinary storage in an icebox at about 0°C seems to be quite satisfactory even if the relative humidity is as high as 75 %. From the figures given in Fig. 14, one can draw the conclusion that storage at room temperature and a relative humidity below 50 % will be safe. However, this is unsuitable for several reasons. A too severe drying of the emulsion will always involve the risk of distorsion and peeling. At the same time it may cause an increased photographic density in the emulsion as a whole. This was the case in all the plates stored at 30 % and 13 % RH. These had a density of 0.37 ± 0.02 while other unfaded plates developed at the same time had a density of 0.30 ± 0.02.

The values given for the fading in the different cases can be compared with one another. Fading may, however, differ slightly from batch to batch on account of the marked influence of the water contents of the emulsion. The water contents, in turn, may vary from emulsion to emulsion at the same relative humidity. The agreement with the F values at 12 ± 2 keV$/\mu$ of the previous paper [4] is good.

It would be highly desirable to find a method to prove a track to be faded. If the faded track is supposed to be due to a particle of a certain mass, the MTW of that track could be plotted against the logarithm of the ionization as calculated from the range–ionization curve for this mass. Provided that the fading is severe, the curve obtained in this way would not be parallel to the ordinary MTW–ionization curve valid for that emulsion. However, this difference in inclination was only observed in cases of severe fading and in such cases a combination of small angle scattering, MTW and range would probably give inconsistent results and settle the question. If only one single track is concerned and the suspected fading is slight it is very unlikely that the precision inherent in any of these methods will be sufficient to ascertain the nature of the particle in the energy interval under consideration here.

Summary

Fading of individual proton tracks was determined in Ilford G-5 emulsions as a function of time, temperature, relative humidity, and energy loss. The measurements enclose the intervals 0–2 months, 3–30°C, 13–75 % RH and 3–20 keV/μ ionization loss. A photometric method was used to determine the grain density of individual tracks. The faded tracks were measured in the same emulsion as unfaded comparison tracks. The precautions and corrections needed are discussed. It has been found that the fading is constant in the interior of the emulsion. The fading effect is larger at the surface. The investigation was essentially confined to the constant effect of the interior. Provided that this effect is not too large, the apparent energy absorbed per unit length is diminished by a constant factor independent of the original ionization. The factor depends on the storing conditions. The factor being constant, a faded track will appear as if it were due to a particle lighter than the real one, if compared with unfaded tracks. The apparent mass has been used to characterize the fading and has been given as a function of time, temperature, and relative humidity. The curves give a survey of the progress of fading under different conditions.

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